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SOLPEX Complex for Studies of Solar Radiation in the Soft X-Ray Range

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Abstract—The SOLPEX complex consists of two instruments for recording soft X-ray radiation from the Sun and is a part of the KORTES equipment, which will be installed on board the International Space Station. The first instrument is a fast-rotating multi-crystalagg spectrometer designed to record solar spectra in the range of 0.4–23 Å with a time resolution of no less than 0.1 s. The second instrument is a pinhole camera with a focal length of 58 cm. The camera has a field of viewof 2 × 2 deg, angular resolution of 2 arcmin, and time resolution up to 0.2 s. The energy range is determined by the input filter and is 1–10 KeV; the energy resolution is 0.5 KeV. The combination of these two instruments makes it possible to locate hot solar sources in the corona, determine their speed, and conduct spectral diagnostics.

Keywords: X-ray spectroscopy, solar corona, Bragg spectrometer, pinhole camera

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INTRODUCTION

Solar studies in the soft X-ray part of the spectrum began almost simultaneously with the era of space research. The first experiment to record short-wave radiation of the solar corona was carried out in 1957 on the second artificial Earth satellite [1]. The first X-ray images of the Sun were obtained in 1963–1965 in a series of Soviet and American experiments using pinhole cameras [2, 3]. As the development of solar physics progressed, the focus of space solar research in the 1970–1980s shifted to spectroscopy. This was due to the fact that the plasma temperature in the solar corona during the most active processes reaches millions of degrees, and, as a result, the vast majority of electromagnetic energy is released in the soft X-ray (SXR) range in the lines of multiply charged ions with a high degree of ionization. Since that time, SXR spectroscopy of plasma has become a powerful tool for studying the properties of energy release in the solar corona. A series of space experiments was carried out, which had significant results for solar physics [4–6]. Currently, with the development of vacuum ultraviolet (VUV) and SXR optics, interest in SXR spectroscopy has declined; however, it remains an important tool for studies of processes in coronal plasma.

KORTES EQUIPMENT COMPLEX

The Kortes equipment complex is being developed at the Lebedev Physical Institute (LPI); it is designed to study the solar corona at the International Space Station [7]. Kortes is a multichannel instrument, which includes eight independent devices (Table 1).

The Kortes equipment is currently planned to be put into operation in orbit in 2024, which corresponds to the period of maximum solar activity. Therefore, the main objective of the experiment is to study flare processes on the Sun, which are characterized by large volumes of released energy, fast development times, and high plasma temperatures. The studies are planned to be carried out using the imaging spectroscopy method, which consists in recording these processes with spectral and imaging instruments simultaneously. Since solar flares are rather difficult to predict, a quasi-continuous mode of observation of the full solar disk with a high temporal resolution will be used for their detection.

The T1–T3 telescopes are designed to record structures in a wide temperature range from 20000 degrees to 1.4 million degrees at corresponding altitudes from the chromosphere to the near corona. A specific feature of the T1 telescope is that this spectral range contains an intense Fe XXIV ion line with an excitation temperature of 10 million degrees, which is typical for flares.

Table 1. Composition of the Kortes equipment complex

Channel	Spectral range	Designation
T1 telescope	195 Å	Corona and flare images
T2 telescope	304 Å	Transition layer images
T3 telescope	584 Å	Chromosphere images
S1 spectroheliograph	180–210 Å	Spectra of the full solar disk
S2 spectroheliograph	280–335 Å	Spectra of the full solar disk
Mg spectroheliograph	8.42 Å	Images of flares and active regions in the Mg XII ion line
RDS spectrometer	0.3–22.8 Å	Spectra of flares and active regions
PHI pinhole camera	0.5–15 KeV	Images of flares and active regions

Thus, this channel is necessary for a comprehensive study of flares using spectroheliographs and spectrometers.

The S1 and S2 spectroheliographs record the full solar disk. They have a spectral resolution of ~0.03 Å per cell and spatial resolution of approximately 3 arcsec in the perpendicular direction. Due to the observation of the entire solar disk, such tools are much more informative and convenient for recording flare spectra than slit spectrometers. Information on the spatial configuration of the structures under study will be obtained from telescopes T1 and T2.

The Mg spectroheliograph is a monochromatic instrument, which records the images of solar structures with temperatures above 4 million degrees in the line of the Mg XII doublet. The significance of this channel is that it localizes the position of only hot sources in the corona.

The RDS spectrometer and the PHI camera are combined into the SOLPEX complex, which is being developed at the Solar Physics Department, Polish Academy of Sciences [8]. The entire Kortes complex is controlled by an onboard computer located inside the sealed compartment of the service module of the ISS Russian segment.

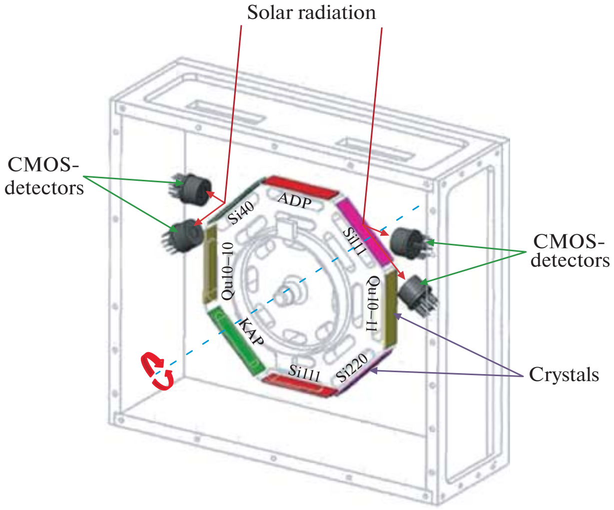

Fig. 1. Schematics of the RDS instrument.

ROTATING DRUM SPECTROMETER (RDS)

The rotating drum spectrometer (RDS) is designed to obtain solar spectra in the range of 0.3–22.9 Å with a spectral resolution of 0.11–1.1 mÅ, depending on the subrange, and a time resolution of approximately 0.1 s. The recorded spectral range mainly includes lines of multiply charged ions with a high degree of ionization, which is characteristic of flare processes. The spectral information from the RDS will be supplemented by the spectral information from the S1 and S2 spectroheliographs, as well as images of the T1 telescope, Mg spectroheliograph, and the PHI camera.

The principle of the instrument is based on the Bragg diffraction of X-rays by crystals. Four pairs of flat crystals in an RDS are mounted on a rotating drum. Diffracted radiation is detected using silicon solid state drift detectors (SDDs). The electronic path of the instrument allows recording the exact position of a pair of crystals and the detection time of each photon, which provides information about its energy.

The schematics of the instrument are shown in Fig. 1. The types of crystals used in the spectrometer and the corresponding spectral ranges are presented in Table 2. The SDDs used in the instrument include one front detector KETEK VITUS H18LE with a window made of AP3.3 polymer and three KETEK VITUS H50 detectors with a beryllium window 12.5 μm thick.

PINHOLE IMAGER (PHI)

A pinhole camera is a simple optical instrument the input aperture of which is a small opening in a nontransparent material. A pinhole camera has several advantages over other optical systems: ease of manufacturing and adjustment, reliability, absence of chromatic aberrations, and spectrum-independent transmission.

Although pinhole cameras were used in X-ray astronomy as far back as the 1960s [2, 3], their use in

Table 2. Parameters of the RDS channels

Channel (number of crystals)	Spectral range (Å)	Spectral resolution (mÅ)	Crystal	Slice	2d (Å)
Front detector					
1(1)	1.678–2.330	0.11	Si	400	2.715
2(1)	2.375–3.295	0.15	Si	220	3.840
3(2)	3.878–5.381	0.25	Si	111	6.2715
4(1)	4.133–5.735	0.27	Quartz	10–11	6.684
5(1)	5.265–7.306	1.3	Quartz	10–10	8.514
6(1)	6.585–9.137	1.3	ADP	101	10.648
7(1)	16.474–22.859	6.5	KAP	001	26.640
Rear detector					
1(1)	0.442–1.618	0.15	Si	400	2.715
2(1)	0.625–2.288	0.22	Si	220	3.840
3(2)	1.021–3.737	0.36	Si	111	6.2715
4(1)	1.088–3.983	0.38	Quartz	10–11	6.684
5(1)	1.386–5.073	0.49	Quartz	10–10	8.514
6(1)	1.734–6.345	0.61	ADP	101	10.648
7(1)	4.337–15.875	1.5	KAP	001	26.640

modern research may be required if a detector with energy resolution and calibrated recording efficiency is used. In this case, a pinhole camera makes it possible to simultaneously obtain solar images, the spectrum of the radiation forming the image, and its photometry.

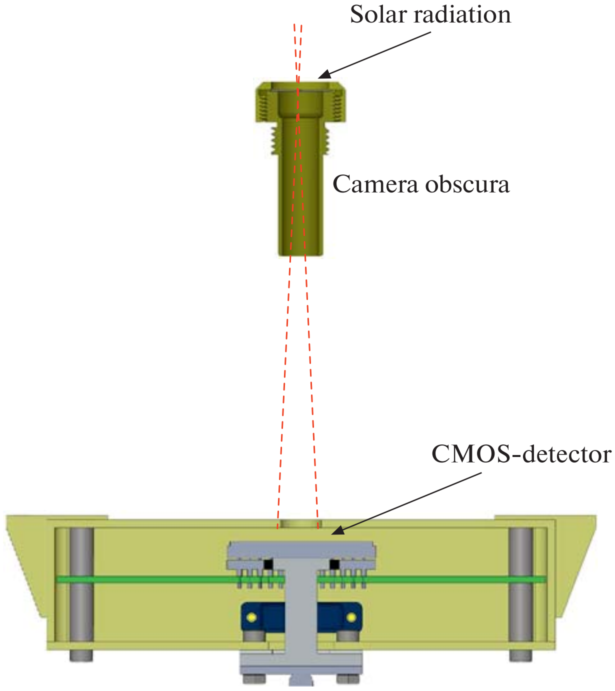

Fig. 2. Schematics of the PHI instrument.

Such an approach is implemented in the PHI channel the schematics of which is shown in Fig. 2. Its key element is an X-ray detector the role of which is played by a Gpixel Gsense 400BSI CMOS sensor with a format of 2048 × 2048 cells and cell size of 11 × 11 μm. Measurements showed that this detector has an energy resolution of approximately 0.5 KeV in the range of 1–10 KeV. A specific feature of this sensor is its short read time (~0.2 s) and high radiation resistance, which allows abandoning a mechanical shutter when recording images.

The input aperture is located at a distance of 580 mm from the plane of the detector and is made as a lead disk with a hole of 0.7 mm diameter closed by a polyamide film 15 μm thick. This configuration of the PHI provides a 2× 2° field of view and angular resolution of approximately 20 arcsec.

The main purpose of the instrument is the localization of hot sources, their photometry, and acquisition of additional spectral information.

CONCLUSIONS

The RDS and PHI instruments included in the SOLPEX complex of the Kortes equipment are a development of the traditional X-ray imaging spectroscopy technique. The combination of these instruments makes it possible to obtain images of active processes on the Sun simultaneously with spectral information on the plasma formed as a result of these processes. This combination is extremely important for analyzing the energy transformation during these processes, determining their strength, and clarifying the chemical composition of the plasma. The high temporal resolution of these instruments will make it possible to study the dynamics of flares and flare-related processes in the solar corona.

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CONFLICTS OF INTEREST

The authors declare that they do not have any conflicts of interest.

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